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COMBINING TRAFFIC SAFETY EXPOSURE INDICATORS IN A COMPOSITE EXPOSURE INDEX

ABSTRACT

The problem of choosing only one relevant safety performance indicator for the purpose of comparing and assessing road safety situations has been the subject of many recent research studies. This paper shows the concept of creating a composite exposure index based on available data. The procedure of creating a model for calculating this indicator is based on the analysis of quality of individual exposure indicators and the size of their impact on the direct safety performance indicators – number of road crashes and their consequences. The following four models (TOPSIS EQUAL, TOPSIS CRITIC, PROMETHEE EQUAL, PROMETHEE CRITIC) for determining weighted coefficients of the individual indicators that participate in the creation of the composite exposure index have been analysed in this paper. The method used for defining the composite exposure index is the "high-efficiency method" based on which the final shape of the model for defining the composite exposure index has been defined. The main aim of this paper is to create a model for defining the composite index of traffic exposure. The final outcome is to provide an opportunity to evaluate and rank traffic safety levels based on the unique road traffic risk.

KEYWORDS

exposure; indicators; risk; TOPSIS; PROMETHEE.

1. INTRODUCTION

Road safety management requires continuous measurement and monitoring of a road safety situation in an area. Therefore, these measurements must be as accurate as possible. The lack of knowledge of data on safety performance indicators results in the impossibility to define concrete problems, monitor and assess suggested and implemented activities, as well as compare the level of road safety. These are the reasons why taking permanent and continual measurements in the field of road safety should be assigned additional significance and necessity. Various and numerous direct and indirect safety performance indicators, as well as absolute and relative safety performance indicators, are the results of frequently complex measurement processes and procedures in road safety. Although safety performance indicators contain a large amount of information on road accidents and their consequences, not all of them are of equal quality or can be applied in different situations.

Even though the comparison of road safety situations is a useful method for grasping the effects of implemented measures through differences in road safety performance, various areas observed simultaneously may be the subject of mutual comparison. Comparing road safety situations is actually an illustration of an unjustified use of certain indicators. Absolute safety performance indicators relating to road crashes and their consequences contain a large quantity of useful information, but their use does not allow for comparison of road safety levels. In fact, the number of road crashes, fatalities, and injuries, as well as the values of other absolute safety performance indicators, depends on a large number of factors that need not be part of a road traffic system. A higher value of some of the absolute safety performance indicators in an area need not necessarily imply a poorer road safety situation. This may be the consequence of a larger number of population in that area, number of registered motor vehicles, number of kilometres travelled, as well as many other indicators that are considered to be the measures of the population exposure in road traffic. The problem of the lack of possibilities for making comparisons on the basis of the values of absolute safety performance indicators has been overcome by using relative safety performance indicators, or risks [1]. The application of these indicators is the simplest and most commonly used method for making international cross-country comparisons of safety performance indicators [2].

There is a range of various definitions of road traffic risks that are used depending on the need [3]. A general definition of a road traffic risk states that this is an expected outcome of safety on roads taking into account the exposure in road traffic, where the outcome is most often the number of road crashes and their consequences. This general definition defines the risk as a function of the number of road accidents or their consequences and exposure. This function is called the safety performance function [4]. The risks represent the ratio between the number of road crashes or their consequences and various measures of exposures, which quantifies the level of road safety in that manner [3]. The most commonly used measures of exposures for calculating a risk include population size, the number of registered motor vehicles, and the number of kilometres travelled [5]. Having in mind the fact that, in addition to the mentioned risk indicators, there are a huge number of other measures of exposure, it is clear that it is possible to use them as a basis for developing additional various road safety risks.

The multitude of different risks contributes to creating an additional problem related to the selection of the risk whose application is the most justified in concrete conditions. For example, Kukić et al. [6] dealt with the selection of a risk considered as a relevant indicator for presenting a road safety situation at the level of municipalities. The research studies that followed recognised the need for defining an indicator that would combine several different risks in order to overcome the problem of selecting the risk based on which it would be justified to make the ranking of the countries [7]. For the purpose of overcoming this problem, researchers dealt with defining the optimum composite index in order to create the unique safety performance indicator.

Composite index models that combine several indicators from the same or various level of the pyramidal structure of safety performance indicators are well known in literature [8, 9]. Hermans et al. [10] analysed various safety performance indicator weighting methods more than a decade ago, with the aim to create a composite index that would integrate the indicators concerned. Wang et al. [11] suggested several models for assessing safety of drivers and pedestrians that included data on average annual daily traffic (AADT), the number of intersecting roads on the network and the vehicle flow. The model of the unique road safety level assessment in an area including safety performance indicators as the indicators of road users' behaviour, in addition to the most frequently used risks, was defined by Pešić et al. [12]. A very important segment of the analyses related to defining the unique indicator is examining the justified use of some indicators in concrete conditions. Moreover, the aim of some research studies in this field has been to create a composite index relating to one topic or area, such as a road environment risk index, alcohol index, etc.[13, 14]. Within their research study, Chen et al. [15] tackled the problem of developing a range of indicators and their combinations in order to make cross-country rankings and select the best performing one amongst them. The analysis of possibilities for combining the public and traffic risk of road fatalities and injuries into a composite index using several variations of DEA and TOPSIS methods was the subject of research conducted by Rosić et al. [16]. In their research, Tešić et al. [17] developed a model that combined indirect safety performance indicators (share of detected drivers having the permitted blood alcohol content, share of vehicles moving at permitted speeds in urban areas, seat belt wearing rates for front seats in passenger cars and vans, share of passenger cars of up to 6 years of age, share of motorways in the total length of the road network, and share of costs of post-crash care of the injured in the GDP).

Given the above, the research presented in this paper also aimed to define unique indicators that would be able to provide a quality assessment and comparison of a road safety situation. Although the subject of this study are the indicators on which previously developed models are partially based, the paper showed a different approach in resolving the issue of selecting the relevant indicator. More precisely, the models that have been developed so far combine many existing risks and other safety performance indicators into a single one; whereas the analytical procedures used in this paper helped create a composite exposure index in road traffic on the basis of which it would be possible to define a completely new relative safety performance indicator.

2. MATERIAL AND METHOD

2.1 Data

The research shown in this paper involves an analysis of a large number of data systematised in two groups. The first group consists of data relative to exposure indicators in road traffic, whereas the second group includes data on the number of road crashes and the size of their consequences.

The analysed data on exposure in road traffic have been taken from the UNECE (Statistical Database – United Nations Economic Commission for Europe) database and include data on the population size, the number of registered motor vehicles, road network length, passenger kilometres (in millions), tonne kilometres (in millions), vehicle kilometres (in millions), tonnes of transported goods (in thousands), number of passengers transported by bus (in thousands), number of bus journeys offered (in thousands) and number of bus seat-km offered (in millions) [18]. The direct safety performance indicators used in the analysis have also been taken from the UNECE database and they are related to the number of road accidents, number of road fatalities, and number of road injuries in those accidents. Only the exposure indicator data relating to fuel consumption (in tonnes) have been taken from the OECD (OECD Statistics) database [19]. The mentioned international databases combine data for a large number of countries. More precisely, the UNECE database includes 56 countries, while the OECD database contains data from 55 countries. However, depending on the indicator and on the country concerned, a large number of data is missing. Having that in mind, the analysis of the data has been made for the time period from 2000 to 2016. The sample shows the data availability for each of the exposure indicators and it is presented in *Table 1*. For example, for the mentioned time period and for the analysed countries the data regarding the number of inhabitants were the most available data, as expected, so this sample included 850 data. If these data were completely available, the sample size for 56 countries and the 17-year-long period would amount to 952. As the sample is deemed insufficiently big, the exposure indicators relating to the number of bus journeys offered and the number of bus seat-km offered have been excluded from further analysis (*Table 1*).

2.2 Data analysis

Creating a model for calculating the combined road traffic exposure indicator requires a complex analysis of the mentioned data. The analysis has been made using the following five steps:

Step 1 – Testing the correlation between the road traffic exposure indicators and direct safety performance indicators,

Step 2 – Determining the weights of the analysed criteria using the Criteria Importance Through Intercriteria Correlation (CRITIC),

Step 3 – Determining the weighted coefficients and ranking the analysed exposure indicators using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Preference Ranking Organisation METHods for Enrichment Evaluation

Table 1 – Sample size for each road traffic exposure indicator

Road traffic exposure indicators	Sample size	Continue with further analysis
Number of inhabitants	850	yes
Number of registered motor vehicles	780	yes
Road network length	690	yes
Passenger kilometres (in millions)	481	yes
Tonne kilometres (in millions)	669	yes
Vehicle kilometres (in millions)	505	yes
Tonnes of transported goods (in thousands)	600	yes
Number of passengers transported by bus (in thousands)	74	yes
Number of bus journeys offered (in thousands)	7	no
Number of bus seat-km offered (in millions)	15	no
Fuel consumption (in tonnes)	467	yes

(PROMETHEE) for the cases in which those criteria are equally important and for the cases of using the weights of criteria as determined by the CRITIC method,
Step 4 – Valuing the applied methods for determining the weighted coefficients of the individual road traffic exposure indicators and selecting the most efficient method, and
Step 5 – Defining the composite road traffic exposure index.

Step 1

Being the first step of the analysis, testing the correlation between the two groups of indicators is the entry point for further steps. Given that the application of the Kolmogorov-Smirnov test has helped determine the absence of normal distribution ($p<0.05$) of the variables observed, the Spearman's rank correlation coefficient (rho) has been used instead.

The strength of the correlation indicates the level of dependence or the quality of relationship between two indicators. In fact, the obtained values of the correlation coefficients are the values of the alternatives or the exposure indicators in relation to the defined criteria, which are:
- The quality of correlation with the number of road accidents,
- The quality of correlation with the number of fatalities from road crashes, and
- The quality of correlation with the number of the injured in road crashes.

More precisely, the coefficient of the correlation of an exposure indicator with a determined safety performance indicator may be considered a justified indicator for defining the risk on the basis of those two indicators.

Step 2

In order to determine the weights of the criteria concerned using the CRITIC method, normalisation of linear data has been performed using the following expression for the initial matrix of the values of alternatives according to the criteria concerned:

$$r_{ij} = \frac{x_{ij} - x_j^-}{x_j^+ - x_j^-} \tag{1}$$

r_{ij} – normalised value of alternative *i* for criterion *j*,
x_{ij} – value of alternative *i* for criterion *j*,
x_j^+ – maximum value for criterion *j*,
x_j^- – minimum value for criterion *j*.

The CRITIC method used for determining the weights of the criteria belongs to the group of objective methods and is based on the combination of standard deviation of normalised values of alternatives according to the criteria and the correlation coefficients between the criteria themselves [20]. The quality of each criterion is expressed by the quantity of information contained in each of them and is calculated as follows:

$$C_j = \sigma_j \sum_{k=1}^{n} (1 - \rho_{jk}) \tag{2}$$

C_j – quantity of information contained in criterion *j*,
σ_j – standard deviation of normalised values of the alternatives for criterion *j*,
ρ_{jk} – correlation coefficient of criteria *j* and *k*.

Relative importance of each of the criteria analysed is defined using the following expression:

$$w_j = \frac{C_j}{\sum_{j=1}^{n} C_j} \tag{3}$$

w_j – relative importance (weight) of criterion *j*.

Step 3

Determining the weights of the individual exposure indicators and their ranking has been carried out using the TOPSIS and PROMETHEE methods. Both methods have been applied for the case of equal importance of all analysed criteria and for the case of application of weights of the criteria determined by the CRITIC method. Consequently, four scenarios have been considered.

The TOPSIS method enables the ranking of the observed alternatives or exposure indicators, on the basis of the total measure of quality of each indicator. This measure of quality is based on the Euclidean distance of each alternative from the positive ideal and negative ideal solution. The positive ideal solution is the hypothetical alternative that has the best values for each criterion considered, whereas the negative ideal solution is also a hypothetical alternative having the worst values of the criteria concerned. An alternative is deemed to be of better quality if it has the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution [21,22].

The application of the TOPSIS method requires the normalisation of values of alternatives for the criteria concerned. The vector normalisation, as the originally suggested concept [21], has been used in this paper:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (4)$$

r_{ij} – normalised value of alternative *i* for criterion *j*,

x_{ij} – value of alternative *i* for criterion *j*.

The weighting of the initial matrix has been done following its normalisation, which has taken into account the relative weights of the criteria (equal or obtained using the CRITIC method):

$$v_{ij} = w_j \cdot r_{ij} \quad (5)$$

v_{ij} – weighted normalised value of alternative *i* for criterion *j*.

The next step in the application of the TOPSIS method is determining the positive ideal and negative ideal solutions, as well as the distance of alternatives from these two solutions:

$$S_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2} \quad (6)$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} \cdot v_j^-)^2} \quad (7)$$

S_i^+ – distance of alternative *i* from the positive ideal solution,

S_i^- – distance of alternative *i* from the negative ideal solution,

v_j^+ – value of the positive ideal solution for criterion *j*,

v_j^- – value of the negative ideal solution for criterion *j*.

Relative closeness of an alternative to the positive ideal solution, and at the same time, a measure of quality of that exposure indicator, has been determined using the expression below:

$$C_i = \frac{S_i^-}{S_i^- - S_i^+} \quad (8)$$

C_i – relative closeness of alternative (exposure indicator) *i* to the positive ideal solution.

The PROMETHEE method enables ranking of alternatives on the basis of preferences of each alternative in comparison with every second one (pair-wise comparison), according to each criterion analysed [23].

An alternative is deemed dominant over the other one if, according to all criteria, it is at least as good as the other one and at least better than the other one according to one of the criteria, which is actually a preference relationship. The indifference relationship means that all the alternatives are equally good for all the criteria. The third and the most frequent relationship is the incomparability relationship. This relationship indicates the incomparability of alternatives which is the consequence of situations in which one alternative is better than the other one according to some criteria and worse according to other criteria. The role of the PROMETHEE method is to minimise the number of incomparable alternatives and enable their ranking and valuing afterwards.

The preference of one alternative over the other one per criterion observed is determined on the basis of the difference in values of the alternatives for that criterion. The bigger the difference is, the bigger the preference is. The preference is actually the advantage given to an alternative in relation to the other one for that criterion and is expressed in the range from 0 to 1, where 0 is complete absence or non-existence of the preference and 1 is the absolute, strong preference. If an alternative has the preference higher than 0 compared to the other alternative for a certain criterion, then the preference of the second alternative in relation to the first one for that criterion equals 0.

$$P_j(A_i, A_k) = F_j[d_j(A_i, A_k)] \quad (9)$$

$$d_j(A_i, A_k) = x_{ij} - x_{kj} \quad (10)$$

$$0 \leq P_j(A_i, A_k) \leq 1 \quad (11)$$

$P_j(A_i, A_k)$ – Preference of alternative *i* in relation to alternative *k* for criterion *j*,

$d_j(A_i, A_k)$ – Difference in values of alternatives *i* and *k* for criterion *j* (x_{ij}-x_{kj}),

$F_j[d_j(A_i, A_k)]$ – Function of preference of alternative *i* in relation to alternative *k* for criterion *j*.

Six different preference functions have been used in this method. One preference function has been selected for each criterion, whereas the following parameters have been defined for each preference function – indifference threshold, strong preference threshold, and inflection point, if any.

For the purpose of the analysis shown in this paper and within the application of the PROMETHEE method, the Gaussian preference function (*Figure 1*) with the inflection point (s) at 0.5 has been used.

$$P(d) = \begin{cases} 0, & d \leq 0 \\ 1 - e^{-\frac{d^2}{2s^2}} & d > 0 \end{cases} \quad (12)$$

The results of the pair-wise comparison of values of alternatives are matrixes of preference functions for each criterion.

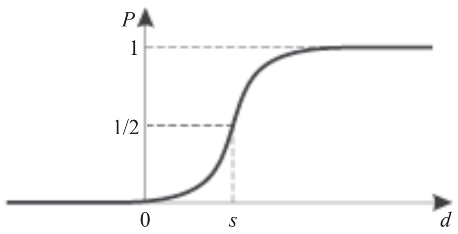

Figure 1 – Gaussian preference function

The index of preference between two alternatives indicates the total preference of an alternative in relation to the other one by taking into account all the criteria simultaneously, as well as their relative weights:

$$\pi(A_i,A_k)=\sum_{j=1}^{n} w_j P_j(A_i,A_k) \tag{13}$$

$\pi(A_i,A_k)$ – Index of preference of alternative *i* in relation to alternative *k*.

The index of preference of an alternative in relation to the other one also takes the values from the range 0–1, where the value of 0 indicates a weak total preference and the value of 1 is a strong total preference. The sum of the mutual preference indexes of two alternatives belongs to the same value range. The preference index of an alternative in relation to itself amounts to 0.

Determining the positive and negative flow of the alternative dominations is the next step in the application of the PROMETHEE method. The positive (outgoing) alternative domination flow is the domination or strength of that alternative in relation to all others. Domination of all other alternatives in relation to one alternative is the negative (incoming) domination flow.

$$\Phi^{+}(A_i)=\frac{1}{m-1}\sum_{k=1}^{m}\pi(A_i,A_k) \tag{14}$$

$$\Phi^{-}(A_i)=\frac{1}{m-1}\sum_{k=1}^{m}\pi(A_k,A_i) \tag{15}$$

$\Phi^{+}(A_i)$ – Positive (outgoing) domination flow of alternative *i*,

$\Phi^{-}(A_i)$ – Negative (incoming) domination flow of alternative *i*.

The total domination flow of an alternative is the difference between the positive and negative domination flow of that alternative, representing the measure of quality of that alternative:

$$\Phi(A_i)=\Phi^{+}(A_i)-\Phi^{-}(A_i) \tag{16}$$

$\Phi(A_i)$ – Total domination flow of alternative *i*.

An alternative is of better quality if its total domination flow is bigger. If one alternative has the total domination flow value higher than any other alternative, the former is assumed to be preferential in relation to the latter. Two alternatives are equally good if their total preference flows have the same value.

The Visual PROMETHEE software has been used for the purposes of the analysis shown in this paper, with regard to the application of the PROMETHEE method.

Step 4

Testing the applied methods has been conducted using the sample including the countries for which the complete data have been provided, i.e., data on all exposure indicators and all the analysed direct safety performance indicators. Based on the obtained weighted coefficients, the composite road traffic exposure index has been determined for each analysed scenario. The method used in the first step of the analysis for testing the correlations between the individual exposure indicators and direct safety performance indicators has been also applied in this step in order to make the analysis of correlation between the composite exposure index and safety performance indicators. Using the values of the correlation coefficients and significance of the criteria determined by the CRITIC method, each method applied, or each scenario analysed therein, has been assessed for its efficiency.

Step 5

Creating the composite road traffic exposure index has been the final step in this analysis. A composite exposure index is the aggregated value of all analysed exposure indicators, obtained by means of the linear aggregation method. The values of exposure indicators that form the composite index must be normalised using the weights that are determined on the basis of applying the most efficient method. The composite exposure index is calculated using the following expression:

$$CEI=\sum_{i=1}^{m} C_i NVEI_i \tag{17}$$

CEI – composite exposure index,

$NVEI_i$ – normalised value of exposure indicator *i*.

3. RESULTS

Testing the correlation between the exposure indicators, on the one hand, and indicators relating to the number of road accidents and their

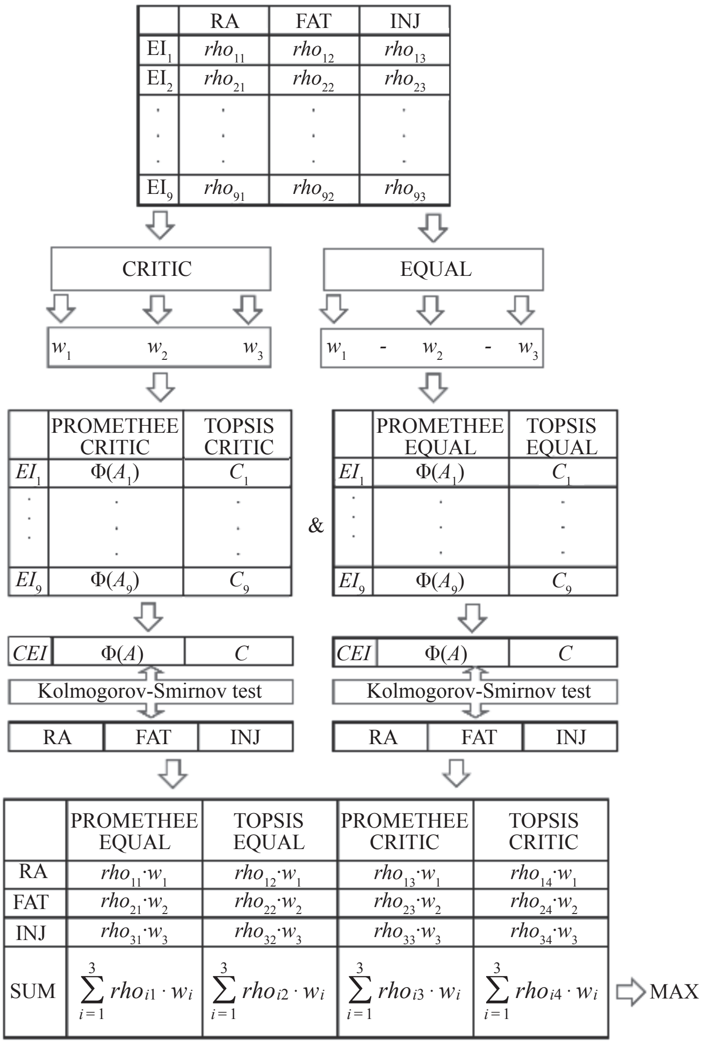

Figure 2 – Model flow diagram

consequences, on the other hand, aims to determine the significance of these correlations and of their strengths, too. The obtained correlation coefficients are input data to be used in further analysis and indicate the quality of correlations between the two mentioned groups of indicators. A stronger correlation indicates a greater dependence between the road traffic exposure expressed by the indicator observed and the safety performance indicators. The number of road crashes, fatalities, and injuries is to a greater extent determined by the road traffic exposure indicators which participate in the making of stronger correlations.

As for the correlations between the analysed road traffic exposure indicators and the number of road crashes, number of road fatalities and number of road injuries, it is important to mention that a correlation with the significance of $p \leq 0.01$ has been recorded in all the relationships. As expected, the positive correlation or the positive value of the correlation coefficient has been present in all the cases. Such a result is in line with the logical assumption according to which the increase in exposure in road traffic contributes to the increase in the number of road accidents and their consequences. Another highly significant result of this part of the analysis is a very strong correlation between all the observed exposure indicators, with the exception of the number of passengers transported by bus and the three direct safety performance indicators. When it comes to the indicator relating to the number of passengers transported by bus, a very strong correlation has been recorded in relation to the number of road fatalities. Nevertheless, the relationships between this indicator and indicators related to the number of road crashes and the number of the injured belong to the group of correlations of medium strength (*Table 2*).

Table 2 – Correlation coefficient between the analysed road traffic exposure indicators and direct safety performance indicators

Road traffic exposure indicators	Number of RA	FAT	INJ
Number of inhabitants	0.882*	0.918*	0.856*
Number of registered motor vehicles	0.879*	0.734*	0.867*
Road network length	0.753*	0.687*	0.746*
Passenger kilometres (in millions)	0.841*	0.648*	0.834*
Tonne kilometres (in millions)	0.844*	0.746*	0.832*
Vehicle kilometres (in millions)	0.793*	0.607*	0.788*
Tonnes of transported goods (in thousands)	0.850*	0.740*	0.841*
Number of passengers transported by bus (in thousands)	0.463*	0.610*	0.430*
Fuel consumption (in thousands)	0.859*	0.716*	0.857*

** Correlation is significant at the level of $p \leq 0.01$.*

As far as the number of road accidents and the number of road fatalities are concerned, the exposure indicator relating to the number of inhabitants has a slightly stronger correlation than other exposure indicators. Such a result indicates that these two indicators are to the highest degree dependent on the population size. However, it is important to say that dependence on other exposure indicators is also very high. The exposure indicator that determines the number of road injuries in road crashes to the highest degree is the number of registered motor vehicles. As for the other two direct safety performance indicators, almost all exposure indicators largely affect the number of the injured in road accidents (*Table 2*).

The use of the CRITIC method for the linearly normalised values of the correlation coefficients has helped determine the weighted coefficients of the three criteria observed for assessing the significance of the exposure indicators. The obtained values of the weighted coefficients for the criteria concerned indicate that the highest significance is given to the correlations made between the exposure indicators and the number of road fatalities (0.445). A little less significant criterion is the quality of correlation with the number of the injured (0.348), whereas the quality of the correlation between the exposure indicator and the number of road accidents is the criterion with the lowest weight (0.207). The determined weights of the criteria enable weighting of values of the exposure indicators per criterion, offering thereby a higher significance to the exposure indicators with higher values for more significant criteria (*Table 3*).

The weighted coefficients of the exposure indicators have been determined using the TOPSIS and PROMETHEE methods, for the case of equal significance of all criteria and the case of the criteria weights defined by the CRITIC method. The weights obtained are those with which individual indicators participate in the creation of the composite exposure index. These weights actually represent the relative significance of each indicator that enables their ranking. The ranks of all the exposure indicators are identical for both scenarios based on the TOPSIS method, whereas the ranking of the indicators based on the PROMETHEE method has some deviations. However, the obtained values of the weighted coefficients are far more significant for the creation of the composite exposure index than the ranks (*Table 4*).

Table 3 – Weights of criteria determined by means of the CRITIC method

Criteria	Criteria weights
Quality of relationship with the number of RA	0.207
Quality of relationship with the number of FAT	0.445
Quality of relationship with the number of INJ	0.348

Valuing the methods applied was done on the basis of the obtained correlation coefficients between the composite exposure index for each scenario and direct safety performance indicators. The obtained correlation coefficients or the values of the alternatives (methods) for the analysed criteria, as well as the weights of the criteria, determine the total efficiency of each method.

The results presented in the paper show that out of four analysed scenarios, the most successful method is the method based on the TOPSIS method and on valuing the criteria using the CRITIC method. The overall usefulness and efficiency of this method on the scale from 0 to 1 is 0.89, whereas slightly less successful is the second scenario based on the TOPSIS method (0.88). Valuing the exposure indicators

Table 4 – Weights of the analysed exposure indicators and their ranks depending on the method applied

Road traffic exposure indicators	TOPSIS-EQUAL		TOPSIS-CRITIC		PROMETHEE-EQUAL		PROMETHEE-CRITIC	
	Weight (C_i)	Rank	Weight (C_i)	Rank	Weight (C_i)	Rank	Weight (C_i)	Rank
Number of inhabitants (PI_1)	0.98	1	0.98	1	1.00	1	1.00	1
Number of registered motor vehicles (PI_2)	0.75	2	0.67	2	0.85	2	0.78	2
Road network length (PI_3)	0.58	7	0.51	7	0.73	7	0.67	7
Passenger kilometres (in millions) (PI_4)	0.65	6	0.55	6	0.79	6	0.71	6
Tonne kilometres (in millions) (PI_5)	0.74	3	0.67	3	0.83	4	0.77	3
Vehicle kilometres (in millions) (PI_6)	0.57	8	0.47	8	0.73	8	0.64	8
Tonnes of transported goods (in thousands) (PI_7)	0.74	4	0.67	4	0.83	3	0.77	3
Number of passengers transported by bus (in thousands) (PI_8)	0.00	9	0.01	9	0.00	9	0.00	9
Fuel consumption (in tonnes) (PI_9)	0.72	5	0.64	5	0.83	4	0.76	5

Table 5 – Overall efficiency of the methods applied

Method	Quality of relationship with the number of RA	Quality of relationship with the number of FAT	Quality of relationship with the number of INJ	Overall efficiency of the methods applied
TOPSIS-EQUAL	0.881*	0.880*	0.870*	0.88
TOPSIS-CRITIC	0.903*	0.887*	0.892*	0.89
PROMETHEE-EQUAL	0.848*	0.855*	0.835*	0.85
PROMETHEE-CRITIC	0.848*	0.855*	0.835*	0.85

** Correlation is significant at the level of $p\leq0.01$.*

was done using the PROMETHEE method in both scenarios and consequently these scenarios have the same value of successor efficiency of the indicators, amounting to 0.85 (*Table 5*).

Having in mind the values of the weighted coefficients of the individual exposure indicators obtained by means of the most successful scenario, the model for calculating the combined road traffic exposure indicator would have the following form:

$$\begin{aligned} CEI = {} & 0.98 \cdot NVEI_1 + 0.67 \cdot NVEI_2 + 0.51 \cdot NVEI_3 \\ & + 0.55 \cdot NVEI_4 + 0.67 \cdot NVEI_5 + 0.47 \cdot NVEI_6 \\ & + 0.67 \cdot NVEI_7 + 0.01 \cdot NVEI_8 + 0.64 \cdot NVEI_9 \end{aligned} \quad (18)$$

Speaking of the concrete model, it is important to say that the model in the given form is applicable only in the situations when all the units (countries) observed have available data for all nine exposure indicators included in the model. The used databases contain data on each exposure indicators for 2015 only for the following six countries: Bulgaria, the Czech Republic, Finland, Latvia, Lithuania, and Poland. The highest value of the composite exposure index among these countries is for Poland (1.402), whereas the smallest exposure is recorded for Latvia (0.088). The value of the composite exposure index for Bulgaria is 0.156, for the Czech Republic 0.397, for Finland 0.266, and for Lithuania 0.142. The exposure of population in road traffic observed does not have any practical value for road safety. However, exposure of population in road traffic determined in that way is the basis for calculating the unique risk and consequently the rating and comparison of road safety situations. The problem of lacking data on some exposure indicators for certain units subject to observation can be overcome by modifying the model defined or eliminating the members of the model for which there are no data for all the units that need to be observed.

4. CONCLUSION

The aim of the analysis conducted in this paper was to define the composite exposure index that combines a large number of individual indicators in the best possible way. The analysis was based on two different methods with two variations each. The selection of the model was carried out during the procedure of testing the model's efficiency. The model was deemed the best representative of various road traffic exposure indicators, making at the same time a significant impact on the values of the direct safety performance indicators. Road traffic exposure expressed by the model defined shows a very big dependence of safety performance indicators relative to the number of road accidents, fatalities, and injuries. The fact that direct safety performance indicators largely depend on or make stronger correlations with the new exposure indicator than it is the case with individual indicators, represents a significant efficiency indicator of the model defined for calculating the composite exposure index.

The application of the defined model enables calculating the risk on the basis of the indicators combining various exposure indicators. Thus, possibilities were provided for overcoming the problem of selecting a suitable relative indicator that should be used when comparing the levels of road safety.

One of the limitations of this study is the lack of data on the values of some exposure indicators, depending on the country and year. Also, the unadjusted method of collecting these data in various countries is a significant limitation both of this study and other research studies conducted in this field. Overcoming these limitations requires huge systemic undertakings.

Future research studies should consider the possibility of improving the proposed model, as well as the possibility of its application at the level of territorial areas smaller than countries. In addition to testing the justified use of indicators included in the proposed model, researchers should also consider possibilities for modifying the existing and defining new criteria. Also, the use of some other methods may contribute to defining a more efficient model.

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KOMBINOVANJE POKAZATELJA IZLOŽENOSTI U SAOBRAĆAJU U KOMPOZITNI INDEKS IZLOŽENOSTI

ABSTRAKT

Problem odabira samo jednog relevantnog pokazatelja bezbednosti saobraćaja, kada je reč o poređenju i oceni stanja bezbednosti saobraćaja, predstavlja u poslednje vreme predmet mnogobrojnih istraživanja. Primenom dostupnih podataka o izloženosti u saobraćaju, u radu je predstavljen koncept formiranja objedinjenog pokazatelja izloženosti. Postupak kreiranja modela za izračunavanje ovog pokazatelja se zasniva na analizi kvaliteta pojedinačnih pokazatelja izloženosti i veličini njihovog uticaja na broj saobraćajnih nezgoda i njihovih posledica. Analizirana su četiri metoda (TOPSIS EQUAL, TOPSIS CRITIC, PROMETHEE EQUAL, PROMETHEE CRITIC) za određivanje težinskih koeficijenata pojedinačnih pokazatelja koji učestvuju u formiranju objedinjenog pokazatelja. Metod na osnovu kojeg je definisan objedinjeni pokazatelj izloženosti sa najvećim uticajem na direktne pokazatelje bezbednosti saobraćaja predstavlja tzv. "metod najveće uspešnosti", i na osnovu njega je definisan konačan oblik modela za definisanje objedinjenog pokazatelja izloženosti u saobraćaju. Glavni cilj istraživanja prikazanog u radu jeste kreiranje modela za definisanje objedinjenog pokazatelja izloženosti u saobraćaju. Konačan ishod rada jeste pružanje mogućnosti za ocenu i rangiranje nivoa bezbednosti saobraćaja na osnovu jedinstvenog rizika bezbednosti saobraćaja.

KLJUČNE REČI

izloženost; pokazatelji; rizik; TOPSIS; PROMETHEE.

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